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SUMER/SOHO

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Abstract. The Solar and Heliospheric Observatory (SOHO), a project of international cooperation between ESA and NASA, was launched on December 2, 1995 and arrived at its operational location (the L1 Lagrangian point, 1.5×10^6 km away from us) on February 14, 1996. It carries twelve sophisticated instruments to examine (1) the hidden solar interior, using the techniques of helioseismology, (2) the heating mechanisms of the solar corona, and (3) the origin of the solar wind and its acceleration processes. A very brief presentation is made on the status report of SOHO - three helioseismology instruments (GOLF, VIRGO and MDI/SOI) providing unique data to study the Sun from its deep core to the convection zone, five remote sensing instruments (CDS, SUMER, EIT, UVCS and LASCO) viewing the solar atmosphere and four instruments (SWAN, CELIAS, COSTEP and ERNE) making *in-situ* measurements of the solar wind and energetic particles. A detailed presentation is made on the rich source of high-resolution EUV observations currently being made and analysed from the SUMER (500-1610Å) instrument by observers from all over the world at the EOF and EAF at NASA-GSFC.

Key words: SUMER/SOHO, solar EUV, spectroscopic diagnostics for solar ions, solar plasma diagnostics, EUV spectroscopy

1. Solar and Heliospheric Observatory

The Sun, our nearest star, is currently studied in unprecedented detail from SOHO (Solar and Heliospheric Observatory) - ESA/NASA spacecraft successfully launched on December 2, 1995. "SOHO" was also a medieval Anglo-French hunting cry, but this time the hunt is for answers to basic questions about the Sun. It carries twelve sophisticated telescopes and other instruments (cf., Fleck et al. 1995) and flies in an elliptical, or "halo" orbit around the Lagrangian point, with an orbit radius of about 600,000km, allowing the spacecraft to experience perpetual day (no night time for SOHO). Thus we have an uninterrupted view of the Sun with SOHO, producing an extraordinary amount of data, twenty four hours a day and seven days a week (cf., Figure 1). The SOHO mission has three principal scientific objectives : (1) study of the structure and dynamics of the solar interior, (2) study of the heating mechanisms of the Sun's million-degree atmosphere, and (3) investigation of the solar wind, its origin, and its acceleration processes. Taking the pulse of the Sun from three helioseismology experiments on board SOHO is a unique opportunity to illuminate the unseen depths of the Sun. Two of them namely, GOLF (Global Oscillations at Low Frequency) and VIRGO (Variability of solar Irradiance and Gravity Oscillations) emphasize global, long-period oscillations and sound waves that can penetrate the deep solar interior. The third instrument, SOI/MDI (Solar Oscillations Investigation/Michelson Doppler Imager) obtains data for oscillations on smaller spatial scales with unprecedented precision.

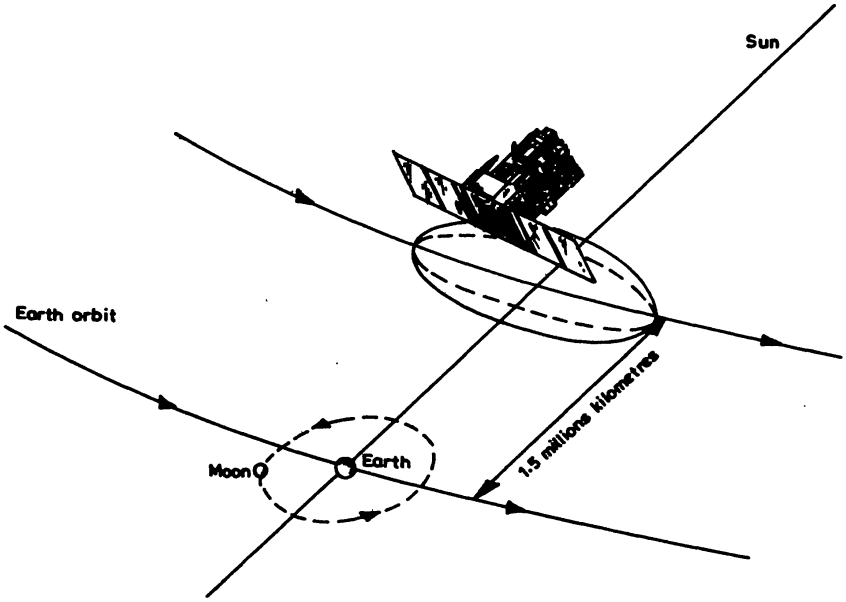

Figure 1. SOHO in an elliptical, or "halo" orbit around the Lagrangian point.

Five instruments on board SOHO tune in the Sun's atmosphere. Three of them namely, SUMER (Solar Ultraviolet Measurements of Emitted Radiation), CDS (Coronal Diagnostic Spectrometer) and EIT (Extreme-Ultraviolet Imaging Telescope) study the chromosphere, the transition region into the low corona. The other two instruments namely, UVCS (Ultraviolet Coronagraph Spectrometer) and LASCO (Large Angle and Spectrometric Coronagraph) examine the middle corona between 1.1 and 10 to 30 solar radii from the Sun-center. SUMER, CDS, EIT and UVCS tune into the different parts of the solar atmosphere by isolating UV or EUV radiation of just one wavelength and forming an image there. Certain UV and EUV lines act like thermometers, specifying the temperature where they are formed, while others are sensitive to the local density. Velocities of moving material are inferred from wavelength shifts or broadenings of the lines. Temperature, density and velocity measurements from all four experiments are used to specify heating, flows and wave motions in different structures and at various levels in the solar atmosphere. First combined results from these experiments uniquely describe an unseen world of violent changes, extreme temperatures and powerful explosions, quite unlike the bland white-light face of the Sun. LASCO uses an occulting disk to mask the Sun's photosphere and view the dim visible sunlight scattered by free coronal electrons. Since the sky's light confuses such images, the finest detail is obtained from space where the daytime sky is truly and starkly black. The LASCO instrument contains three such coronagraphs with nested and overlapping annular fields of view from 1.1 to 30 solar radii from the Sun-center, looking closer to, and further from, the Sun than all previous space-borne coronagraphs.

Coronal remote sensing and *in situ* experiments on board SOHO provide a comprehensive data set to study the solar wind from its source at the Sun to the Earth. As mentioned above, UVCS and LASCO experiments determine temperature, density and velocity information in regions near the Sun where the solar wind is accelerated and has its origin. Three SOHO instruments namely, CELIAS (Charge, Element and Isotope Analysis System), COSTEP (Comprehensive Suprathermal and Energetic Particle analyser) and ERNE (Energetic and Relativistic Nuclei and Electron experiment) analyze *in situ* the charged particles in the solar wind. The remaining instrument SWAN (Study of Solar Wind Anisotropies) map out the wind's large-scale structure. First results from SOHO will shortly appear in Solar Physics. For want of space, we only discuss the high-quality EUV observation from SUMER in the following section. Forbidden lines observed by SUMER is given in section 3. A brief presentation is made in section 4 on SUMER science. We give concluding remarks in the last section.

2. EUV Observation from SUMER

The SUMER instrument received its first light on January 24, 1996 and obtained a detailed spectrum with detector B (cf., Wilhelm et al. 1995 for description of the instrument) in the wavelength range from 660 to 1490 Å (in 1st order) inside and above the limb in the north polar coronal hole. This range was later extended to 1610 Å using detector A of the instrument.

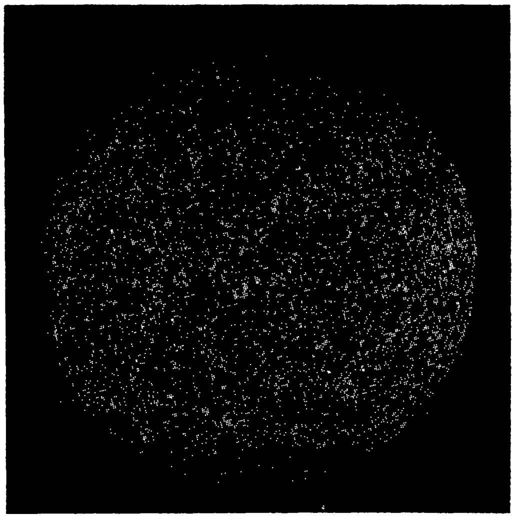

Figure 2. Sun in the emission line of neutral helium at 584.3 Å taken by the SUMER on March 4, 1996 (courtesy, SUMER team).

Table. 1. Line identifications in the range between 903.6235 and 942.538 Å (cf., Wilhelm et al. 1996).

λ (Å)	Line	λobs (Å)	Transition		
903.6235	C II	Ref. Line	$2s^22p\ ^2P_{1/2}$	–	$2s2p^2\ ^2P_{3/2}$
903.9616	C II	–	$2s^22p\ ^2P_{1/2}$	–	$2s2p^2\ ^2P_{1/2}$
904.1416	C II	–	$2s^22p\ ^2P_{3/2}$	–	$2s2p^2\ ^2P_{3/2}$
904.4801	C II	Ref. Line	$2s^22p\ ^2P_{3/2}$	–	$2s2p^2\ ^2P_{1/2}$
–	H I	913.869	$1s\ ^2S$	–	$21p\ ^2P$
–	H I	914.088	$1s\ ^2S$	–	$20p\ ^2P$
–	H I	914.333	$1s\ ^2S$	–	$19p\ ^2P$
914.576	H I	914.603	$1s\ ^2S$	–	$18p\ ^2P$
914.919	H I	914.944	$1s\ ^2S$	–	$17p\ ^2P$
915.329	H I	915.346	$1s\ ^2S$	–	$16p\ ^2P$
915.612	N II	–	$2s^2 2p^2\ ^3P_0$	–	$2s2p^3\ ^3p_1$
915.824	H I	915.836	$1s\ ^2S$	–	$15p\ ^2P$
915.962	N II	–	$2s^2 2p^2\ ^3P_1$	–	$2s\ 2p^3\ ^3P_0$
916.012	N II	–	$2s^2 2p^2\ ^3P_1$	–	$2s\ 2p^3\ ^3P_2$
916.429	H I	916.439	$1s\ ^2S$	–	$14p\ ^2P$
916.701	N II	–	$2s^2\ 2p^2\ ^3P_2$	–	$2s\ 2p^3\ ^3P_2$
916.710	N II	–	$2s^2\ 2p^2\ ^3P_2$	–	$2s\ 2p^3\ ^3P_1$
917.181	H I	917.180	$1s\ ^2S$	–	$13p\ ^2P$
918.129	H I	–	$1s\ ^2S$	–	$12p\ ^2P$
918.724	O I	–	$2s^2\ 2p^4\ ^3P_0$	–	$2s^22p^3\ 12d\ ^3D_1$
919.351	H I	–	$1s\ ^2S$	–	$11p\ ^2P$
919.7810	Ar II	–	$2s^2\ 2p^5\ ^2P_{3/2}$	–	$2s_2\ ^{2P}6\ 2^S{}_{1/2}$
920.963	H I	–	$1s\ ^2S$		$10p\ ^2P$
921.992	N IV	–	$2s2p\ ^3P_1$	–	$2p^2\ ^3P_2$
922.519	N IV	–	$2s2p\ ^3P_0$	–	$2p^2\ ^3P_1$
923.057	N IV	–	$2s2p\ ^3P_1$	–	$2p^2\ ^3P_1$
923.150	H I	–	$1s\ ^2S$	–	$9p\ ^2P_2$
923.220	N IV	–	$2s2p\ ^3P_2$	–	$2p^2\ ^3P_2$
923.675	N IV	–	$2s2p\ ^3P_1$	–	$2p^2\ ^3P_0$
924.283	N IV	–	$2s2p\ ^3P_2$	–	$2p^2\ ^3P_1$
924.952	O I	–	$2s^22p^4\ ^3P_2$	–	$2s^22p^38d\ ^3D_3$
925.442	O I	–	$2s^22p^4\ ^3P_2$	–	$2s^22p^39s\ ^3S_1$
926.226	H I	–	$1s\ ^2S$	–	$8p\ ^2P$
926.295	O I	–	$2s^22p^4\ ^3P_1$	–	$2s^22p^38d\ ^3D_2$
926.809	O I	–	$2s^22p^4\ ^3P_1$	–	$2s^22p^39s\ ^3S_1$
926.903	O I	–	$2s^22p^4\ ^3p_0$	–	$2s^22p^38d\ ^3D_1$
927.394	O I	–	$2s^22p^4\ ^3P_0$	–	$2s^22p^39s\ ^3S_1$

Table 1 Continued

λ (Å)	Line	λobs (Å)	Transition		
929.5168	O I	Ref. Line	$2s^22p^4\ ^3P_2$	–	$2s^22p^37d\ ^3D_3$
930.2566	O I	–	$2s^22p^4\ ^3P_2$	–	$2s^22p^38s\ ^3S_1$
930.442	Ne VII	–	$2s^2\ ^1S_0$	–	$2s2p\ ^1P_1$
930.748	H I	–	$1s\ ^2S$	–	$7p\ ^2P$
930.8862	O I	–	$2s^22p^4\ ^3P_1$	–	$2s^22p^37d\ ^3D_2$
931.4820	O I	–	$2s^22p^4\ ^3P_0$	–	$2s^22p^37d\ ^3D_1$
931.6282	O I	–	$2s^22p^4\ ^3P_1$	–	$2s^22p^38s\ ^3S_1$
932.0537	Ar II	–	$2s^22p^5\ ^2P_{1/2}$	–	$2s^22p^6\ ^2S_{1/2}$
932.2249	O I	–	$2s^22p^4\ ^3P_0$	–	$2s^22p^38s\ ^3S_1$
933.38	S VI	–	$3s\ ^2S_{1/2}$	–	$3p\ ^2P_{3/2}$
934.703	Fe III	–	$3d^6\ ^3P_2$	–	$3d^54p\ ^3S_1$
935.1930	O I	Ref. Line	$2s^22p^4\ ^1D_2$	–	$2s^22p^34s\ ^1D_2$
935.275	Al II	–	$3s^2\ ^1S_0$	–	$3s4p\ ^1P_1$
936.6295	O I	Ref. Line	$2s^22p^4\ ^3P_2$	–	$2s^22p^36d\ ^3D_3$
937.803	H I	–	$1s\ ^2S$	–	$6p\ ^2P$
937.8405	O I	–	$2s^22p^4\ ^3P_2$	–	$2s^22p^37s\ ^3S_1$
938.0200	O I	–	$2s^22p^4\ ^3P_1$	–	$2s^22p^36d\ ^3D_2$
938.6249	O I	–	$2s^22p^4\ ^3P_0$	–	$2s^22p^36d\ ^3D_1$
939.2346	O I	–	$2s^22p^4\ ^3P_1$	–	$2s^22p^37s\ ^3S_1$
939.8412	O I	–	$2s^22p^4\ ^3P_0$	–	$2s^22p^37s\ ^3S_1$
942.490	He II	–	$2s\ ^2S$	–	$11p\ ^2P$
942.538	He II	–	$2p\ ^2P$	–	$11d\ ^2D$

The 2nd-order spectra of detectors A and B cover 330 to 805 Å and are superimposed on the 1st-order spectra. Many more features and areas of the Sun and their spectra have been observed since then, including coronal holes, polar plumes and active regions. The atoms and ions emitting this radiation exist at temperatures below 2×10^6 K and are thus ideally suited to investigate the solar transition region where the temperature increases from chromospheric to coronal values. SUMER is also operated in a manner such that it makes images or spectroheliograms of different sizes in selected lines. A detailed line profile with spectral resolution elements between 22mÅ and 45mÅ is produced for each line at each spatial location along the slit. From the line width, intensity and wavelength position we are able to deduce temperature, density and velocity of the emitting atoms and ions for each emission line and spatial element in the spectroheliogram. Because of the high spectral resolution and low noise of SUMER, it has been possible to detect faint lines which have not been observed previously and to determine their spectral profiles. The first results of SUMER obtained during the first months of the SOHO mission are described by Wilhelm et al. (1996) and Lemaire et al. (1996). We present the image of the Sun in the emission line of neutral helium at 584.3 Å wavelength taken by the SUMER on March 4, 1996 (Figure 2). In this chromospheric

Table 2. Forbidden lines newly observed by SUMER in a coronal steamer 2 arcmin above the east limb and their relative intensities (cf., Wilhelm et al. 1996).

Ion	$\lambda_{\text{cal.}}$ (Å)	Intensity
Ar XI	1304.9	600
Ar XII	1054.9	500
Al VII	1054.08	50
Si VII	1049.2	200
Ar XII	1018.6	1000
Si IX	950.08	9400
Si VIII	949.24	4000
Si VIII	944.38	9400
S IX	871.73	1600
S X	787.56	1000
S XI	782.96	840
Ar XII	669.97	200
Ar XII	648.93	1000
Ca XIII	648.71	1000

line formed at temperature of about 20,000 K, we see coronal holes and interestingly spicules longer in coronal holes than beneath streamer.

Spectral catalogues of different solar features have been derived from scans over the entire wavelength range of SUMER. They include emissions from neutral atoms and ions of various elements in the temperature range from $T_e = 1\times10^4$ to 2×10^6 K, that means, emission lines and continua emitted from lower chromosphere to the corona. The broad wavelength coverage of SUMER provides important new plasma diagnostics and principal means to deduce physical parameters of the solar atmosphere (cf., Dwivedi, 1994). The spectra acquired by SUMER are a significant improvement over those recorded in the past. They are much richer than previously published spectra and contain lines emitted by neutrals and ions from a large number of elements. Preliminary "working line list" from spectra recorded inside the limb and 2 arcmin above the limb have been compiled. The list covering the disk observations contains wavelengths and peak intensities of over 500 spectral lines in the 680-1175Å -wavelength range. The list with lines above the limb indicates many more lines, of which a fraction has been identified. To identify the rest of the lines, a significant amount of work needs to be done and more basic atomic physics data may be required. Table 1 provides sample of lines present in a 40 Å section centred at 923 Å (cf., Wilhelm et al. 1996). The spectra were observed in a quiet-Sun region, near the limb, and in a coronal streamer 2 arcmin above the limb.

3. Forbidden lines observed by SUMER

Coronal forbidden lines, first recorded during solar eclipses, allowed Edlen and others in 1940s to establish for the first time the temperature of the solar corona. Ever since, such lines have been used in the diagnostics of low-density plasmas in general and in coronal studies in particular. The streamer spectra recorded by SUMER contain forbidden lines with excellent

Table 3. N I iso-electronic sequence (Wilhelm et al. 1996).

	Line	λ_{obs} (Å)	$\lambda_{cal.}$ (Å)	Intensity
$2s^2\,2p^3\,{}^4S_{3/2}$ - ${}^2P_{3/2}$	Mg VI	1190.07	1190.074	100
	Al VII	–	1054.08	50
	Si VIII	–	944.38	9400
	Ar XII	–	648.93	1000
	Ca XIV	–	545.38	?
$2s^2\,2p^3\,{}^4S_{3/2}$ - ${}^2P_{3/2}$	Si VIII	1445.75	1445.753	1100
	Si VIII	1440.50	1440.497	200
	S X	1212.96	1212.970	20000
	S X	1196.24	1196.245	10000
	Mg VI	1191.62	1191.611	500
	Ar XII	–	1054.9	500
	Ar XII	–	1018.6	1000
	Si VIII	–	949.24	4000
	S X	–	787.56	1000
	Ca XIV	–	580.05	?

diagnostic properties. Many of the forbidden lines present in the SUMER wavelength range belong to highly ionized abundant solar ions having $2s^2\ 2p^k$ and $3s^2\ 3p^k$(where k = 1 to 5) ground state configurations. Some of the forbidden lines were previously measured in spectra emitted by the solar corona and by tokamak plasmas. However, many other forbidden lines have been observed for the first time in the SUMER spectra of a coronal streamer. Preliminary identifications and the observed relative intensities of the more intense among the newly observed forbidden lines are given in Table 2. Some of the forbidden lines originating within the ground configuration of N-like ions are expected to be quite intense in streamer spectra, provided the ions are sufficiently abundant in the plasma. Two transitions are shown in Table 3 with their relative intensities as seen by SUMER in the same coronal streamer. The N-like ions Mg^{+5}, Si^{+7}, Ar^{+11} and Ca^{+13} have their peak abundances at electron temperatures of 5×10^5, 8×10^5, 1.3×10^6, 2×10^6 and 3×10^6 K, respectively. The forbidden lines of Si^{+7}, S^{+9} are most intense among the N-like ions in the streamer spectrum, while the Ca XIV lines are barely visible or perhaps not detectable at all, indicating a streamer temperature that peaks near 1×10^6 K. It is most likely that the streamer contains little, if any, plasma at temperatures higher than $T_e=2\times10^6$ K. Intensity ratios of lines emitted by the above mentioned ions are sensitive to electron densities in the range between 10^8 and 10^{11} cm^{-3} (Dwivedi, 1991). Relative intensities of the Si VIII and S X density-sensitive forbidden lines present in a SUMER spectrum are used to deduce plasma densities in the emitting regions.

4. SUMER science

SUMER science has been discussed in greater detail (cf., Dwivedi, 1994, 1996; Dwivedi and Mohan, 1996) and will not be repeated here. However, we should like to emphasize that we have successfully carried out several observing sequences based on our previous work (cf., Dwivedi and Mohan 1995a,b,c). Analysis and interpretation of these observations from SUMER is underway and will be published elsewhere by Dwivedi et al. (1997). Apart from deducing density, temperature and their inhomogeneity in the solar plasma, there is also an interesting new opportunity for EUV spectroscopy to contribute in the other direction by shedding light on a solar phenomenon which is not yet well understood: the First Ionization Potential (FIP) effect. The FIP effect should eventually offer valuable clues into the process of heating, ionization and injection of material into coronal loops as well as into more open coronal field structures.

5. Concluding remarks

In conclusion, the instrument SUMER is providing an enormous amount of high-quality EUV data, not available previously, for better understanding of coronal heating and solar wind acceleration mechanisms, one of the main science goals of the SOHO mission. And observers from all over the globe are busy twenty four hours a day and seven days a week at the EOF and EAF at NASA-GSFC making full use of the SUMER capabilities, taking observations and analysing them to learn more about the Sun - our nearest star.

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